OS, RE, IR, RU, RH, PD, AU IN BOREHOLE SAMPLES FROM THE CLEARWATER EAST CRATER (CANADA) AND THE BOLTYSH IMPACT CRATER (UKRAINE).

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The identification of projectiles of terrestrial impact craters may be deduced from melt rock siderophile and highly siderophile element abundances and interelement ratios. High concentrations of strongly siderophile trace elements have been detected in the East Clearwater melt rocks [1]. Chondrite-normalized ratios and the apparent presence of meteoritic Cr, suggested the presence of around 7% of a chondritic component (nickel concentrations 5 to 10% CI-chondritic abundances) in the impact melt [1].

From Boltysh, so far only eight samples have been analyzed; three contain <1 ng/g Ir and five contain about 0.1 ng/g Ir [2,3]. Grieve et al. [3] concluded that the impactor could have been a stony projectile if the Ni (43 μg/g), Cr (56 μg/g) and Ir enrichments are meteoritic in origin.

The purpose of this study was to better characterize the meteoritic signatures of these two craters by additional analyses of highly siderophile elements (especially the less often analyzed elements Os, Rh and Ru) which can be used to distinguish between magmatic iron meteorites and non-magmatic iron meteorites and chondrites.

Analytical techniques

The HSE were analysed by the fire assay neutron activation method using nickel sulphide as collector, following the analytical procedures described by Schmidt et al. [4]. The INAA procedure involved two irradiations at a thermal neutron flux of $1.7\text{x}10^{12}$ neutrons cm^{-2} sec^{-1} in the RP2 hydraulic rabbit facility of the Mainz TRIGA Reactor: a short (5 minutes) irradiation for Rh and a long (12 hours) irradiation for the other elements.

Characterization of meteoritic components and projectile identification

Clearwater East

Six samples from a Clearwater East drill hole were analysed for PGE, Au and Re. The major element composition of the analysed samples is rather constant [5], in agreement with observations at a large number of terrestrial impact craters. Clearwater East impact melts are highly enriched in Ir and other highly siderophile elements (Ir=25.2$\pm$6.5 ng/g) relative to average upper crust concentrations (0.03$\pm$0.02 ng/g Ir). The amount of meteoritic component corresponds to 4 to 7 % of a nominal CI component. The HSE patterns from Clearwater East are flat with some Re and Au depletion and some Ni, Co and Cr enrichment relative to CI-chondrites. The Ni/Ir and Ni/Co ratios from the magmatic iron meteorite Trenton (IIIAB) are similar than the ratios of the impact melts. The Cr/Ir ratios of the melt samples are higher than the chondritic Cr/Ir ratio and much higher than the Cr/Ir ratio of iron meteorites.

From Clearwater East, one basement sample (quartz- monzonite) has been analyzed to infer the basement contribution to the siderophile element contents of the impact melt. We have found a high Rh (1.71 $\pm$ 0.07 ng/g) content in this sample, to be compared to an average Rh content of about 0.4 ng/g in crustal rocks and around 1 ng/g in mantle rocks. The Rh content in the basement sample agrees with estimates of the indigeneous Rh from an Ir vs. Rh regression (1.82 $\pm$ 1.93 ng/g Rh). After subtraction of this indigeneous component, the Ir/Rh ratio of East Clearwater melts is clearly chondritic. Other siderophiles in the basement sample are in the range of upper crustal abundances.

Similar estimates for indigeneous Pd give a value of 9.00 $\pm$ 5.24 ng/g, much higher than the Pd content of the basement sample DCW-1-64-472 (1.6 $\pm$ 0.1 ng/g). In this sample, Palme et al. [1] found 7.4 ng/g Pd, significantly higher than estimates of crustal rocks and the value obtained in this work. For Ru and Os, which represent well correlated elements (r^2 = 0.99), the y-intercepts are 1.55 $\pm$ 2.53 ng/g and 1.70 $\pm$ 1.03 ng/g, respectively. The content for Ru agrees with estimates of the upper crust, but the Os y-intercept is much higher than the upper crustal content of about 0.05 ng/g. The indigenous components of Os and Pd are difficult to evaluate. A small change in the slope of the Os-Ir and Pd-Ir correlations has a large influence on the corresponding indigenous contributions.

Palme et al. [1] have analyzed two melt samples from this crater for Os and Ir and found Os/Ir ratios of 1.03 (DCW-2-63-1039) and 1.10 (DCW-2-63-980.5). The five impact melt samples here show an excellent correlation of Os and Ir (r^2=0.99) with the Os/Ir ratios in the range of 1.06 to 1.10.

The Re and Au concentrations range from 0.21 to 0.91 ng/g and 3.62 to 7.68 ng/g, respectively. Rhenium has been shown to be volatilized during terrestrial impact processes [6]. The five samples studied in this work may also have lost some Re and Au during terrestrial weathering. The Re concentrations in this study are lower than those obtained by Palme et al. [5]. The average of 5 analyses from Palme et al. [1,5] gives a Ir/Re ratio of 15 $\pm$ 1.7, very similar to the CI-ratio. In contrast, the Re concentration of the basement sample DCW-1-64-472 (0.16 ng/g) from this work is four times higher than the content obtained by Palme et al. [1]. We have no explanation for this discrepancy. In summary: The predominantly chondritic ratios among HSE support a chondritic projectile for the Clearwater East projectile.

Boltysh

Chemically, the melt rocks are relatively homogeneous and correspond to a mixture of Kirovograd granites and gneisses with a ratio of 5 to 1. The bulk composition of the analysed samples is shown in Table 2 by Grieve et al. [3]. The excess siderophiles in the seven borehole samples from Boltysh are very low (Ir = 0.2±0.1 ng/g), barely above the background. The low fraction of meteoritic components in Boltysh impact melts can only be identified by Ir. However, the Rh/Os ratio of Boltysh melts is clearly non-chondritic. Subtracting the unusually high content of 1.3 ng/g of Rh from these samples (upper crustal rocks have around 0.4 ng/g Rh, see Schmidt et al. [4]) does not bring them to the chondritic ratio. There is excess Rh compared to Os and Ir.

The indigeneous content of Pd (2.32 ± 0.30 ng/g) is in aggreement with other estimates of Pd in the upper crust (see Schmidt et al. [4]). Indigenous Ru is more difficult to evaluate. The two samples lowest in Ir show only upper limits for Ru. The five highest samples in Ir have Ru concentrations (Ru = 0.62 ± 0.21 ng/g) in the range of the upper crust. For indigenous Ni and Co, we have taken the concentrations from Grieve et al. [3] (melt samples; Ni=43 μg/g; Co=21 μg/g; Cr=56 μg/g, average of 4 basement samples; Ni=16 μg/g; Co=25 μg/g; Cr=26 μg/g). As pointed out earlier (Schmidt et al. [4]), the identification of Cr as a meteoritic element requires a comparatively high fraction of a meteoritic component, in general more than 3 % of a nominal CI-component. Impact melts should have at least 100 μg/g Cr for identifying meteoritic Cr. Therefore, in the case of the Boltysh impact melt, we can neither confirm nor rule out extraterrestrial Cr.

The HSE pattern from Boltysh is somewhat fractionated relative to CI-chondrites. The amount of meteoritic component corresponds to 0.015 to 0.07% of a nominal CI component. Normalized abundances increase from the refractory to the more volatile siderophile elements (Os $<$ Ir $<$ Ru $<$ Rh $\sim$ Pd $\sim$ Au $\sim$ Ni $\sim$ Co). The magmatic iron meteorites Trenton and Tamarugal have some of the abundance characteristics of the Boltysh pattern as for example, the comparatively high and non-chondritic Ni/Ir- and Ru/Ir-ratios.

The CI-normalized Os abundances of all impact melt samples from the Boltysh crater are lower than those of the other refractory elements. This is reflected in lower than chondritic Os/Ir-ratios in Boltysh samples (Os/Ir ranges from $<$1.43 to $<$0.30; Os/Ir$_{CI}$=1.06).

Low Os/Ir ratios were also observed in analyses of impact melts from three Scandinavian craters (Sääksjärvi, Mien and Dellen [7]). If the low Os/Ir ratios in the analysed melt samples reflect original fingerprints of the projectile, then a magmatic iron meteorite as projectile is likely. However, we cannot exclude loss of Os during the impact. Because of the low siderophile element anomaly and uncertainties in making corrections (correlations are weak) for indigeneous siderophile elements, no clear projectile assignment can be made. References [1] Palme H., Janssens M.-J., Takahashi H., Anders E. and Hertogen J. (1978) *Geochim. Cosmochim. Acta* **42**, 313-323. [2] Gurov E.P., Kolesov G.M., Gurova E. P. (1986) *Meteoritika* **45**, 150-155. [3] Grieve R.A.F., Reny G., Gurov E.P. and Ryabenko V.A. (1987) *Contrib. Mineral. Petrol.* **96**, 56-62. [4] Schmidt G., Palme H. and Kratz K.-L. (1996) *Geochim. Cosmochim. Acta*, submitted. [5] Palme H., Göbel E. and Grieve R. A. F. (1979) *Proc. Lunar Planet. Sci. Conf. 10th*, 2465-2492. [6] Morgan J. W. (1978) *Proc. Lunar Planet. Sci. Conf. 9th*, 2713-2730. [7] Schmidt G., Palme H. and Kratz K.-L. (1995) *LPSC* **XXVI**, 1237-1238.